Chapter 2

Situating the Study:
A Review of Related Research

Introduction

This study addresses three major research problems—to *describe, explain, and assess* the *implementation* and *effectiveness* of GIS technology and methods in secondary education in the United States. In order to describe and explain GIS implementation, the relevant technological, methodological, instructional, sociological, and behavioral issues must be examined. What forces, trends, and practicalities hinder and encourage GIS adoption? To assess the effectiveness of GIS, this study examines other research in GIS and other geographic technology in education.

Because GIS is a set of hardware and software, it must be examined as a set of technological tools. However, Gerber (1992) pointed out that technology involves objects, processes (skills, procedures, techniques), and organization. Furthermore, since GIS entails and even requires a specific set of instructional techniques, it must be examined as a method of instruction. As a technology and a method, the implementation of GIS can be examined within the context of contemporary geography education, characterized by the standards movement, assessment, and technological change.

Just as many disciplines contributed to the development of GIS, addressing the research questions requires bridging several disciplines—educational technology, geographic information science, and geography, particularly the subfield of geography education. Educational technology research shows how technology has been approached and studied in education, particularly its effectiveness. Geographic information science research explains how GIS has developed and provides understanding of some technological catalysts and challenges to its implementation. Reviewing research in geography and geography education provides the historical background that led to the current level of implementation. It will also describe the social and educational catalysts and challenges to implementing GIS in a classroom. I examine theoretical frameworks constructed to address the use of GIS in education, describe methods used to teach GIS, and explore research on the effectiveness of GIS in education. The *implementation* of GIS and the *effectiveness* of GIS will be common threads running through this review of research.

The Implementation of GIS in Secondary Education

Research in GIS Education from the Geographic Information Sciences

Since the 1960s, GIS literature has covered two broad areas. One area of research views GIS as a model, method, approach, and science, seen in research *about* GIS. Research about GIS appears in peer-reviewed geographic journals such as *Cartography and Geographic Information Systems*, and the *International Journal of Geographic Information Science*. Over this time, the field developed from a set of complex tools to what many view as science in its own right (for example, Goodchild 1992). *Geographic Information Science,* or *Geomatics* as it is referred to in many parts of the world, includes geographic information systems, remote sensing, spatial analysis, global positioning systems, and other geographic technologies examined in the broader context of science and society.

The second area of research views GIS as an *application or tool.* Research *using* GIS began to become widespread after 1980, beginning with environmental science and spreading to the social sciences and business. This brought a profusion of application trade journals such as *Geo Info Systems, Business Geographics, and Geo World* at the beginning of the 1990s, as well as conference proceedings from *GIS/LIS,* the Urban and Regional Information Systems Association (URISA), AM/FM International (later, the Geospatial Information Technology Association (GITA)), and the Environmental Systems Research Institute (ESRI).

Research on GIS in education can be found in both of the above groups of literature, but is largely confined to GIS as an application or tool. This means that the bulk of the GIS education literature is not peer-reviewed, and is comprised of anecdotal accounts of the GIS projects and experiences that teachers and schools have had in the curriculum. Even practical books for teachers describing new technologies for education pay no attention to GIS (for example, Bazeli and Heintz 1997; Morrison et al. 1999). GIS is seldom mentioned in reviews of electronic learning tools (for example, Menges 1994). Exceptions do exist in articles designed to raise awareness of GIS, similar to those published when the World Wide Web began, such as Deal (1998), Tinker (1992), Michelsen (1996) and Alibrandi (1997), but their goal is to provide an overview rather than an in-depth analysis of issues or effectiveness of GIS. If this weren't a bleak enough picture of the status of GIS education research, overall, research on GIS in education comprises an estimated less than 1% of research in GIS.

One of the few educational research compendiums to address GIS as an approach was *Human Factors in Geographical Information Systems* (Medyckyj-Scott and Hearnshaw 1993), but it focused on human-computer interface design considerations. Its chapter on learning was limited to mental models about the system and a survey of how users learned to use a GIS. Brown (1996) identified hurdles to the successful implementation of GIS, but she examined local government users, not educators.

Research viewing GIS as an approach is beginning to address the effect of GIS on society (such as Pickles 1995). To encourage more research, the University Consortium of Geographic Information Science (UCGIS) placed “GIS and Society” on its top 10 list of needed areas of research (UCGIS 1997). Although this includes the effect of GIS on large social structures, schools have thus far been largely ignored.

Research in GIS Education from the Geography Education Subfield

The existing research on GIS in education comes largely from the subfield of geography education, rather than from the geographic information sciences, but even in this subfield, the paucity of research is striking. This insufficiency is not confined to research on GIS in education, but is reflective of the lack of geography education research in general. The field has produced only a small amount of research on K-12 geography curriculum and instruction in the United States since 1950 (Hill 1997). Wolforth claimed that “among the various branches of geography, geographical education has the most weakly defined research dimension” (1980: 165).

Nevertheless, some understanding of GIS implementation in education *can* be achieved from the few but insightful research efforts to date. Robust hardware and software requirements and the lack of relevant and accessible data were identified as factors that influence the implementation of GIS (Audet and Paris 1997). Bednarz and Ludwig (1997) suggested that the lack of teacher training and curriculum materials was slowing the rate of GIS adoption. Bednarz and Audet (1999) conducted a survey of 736 members of the Association of American Colleges of Teacher Education to assess the status of preservice teacher education in GIS. They found that only 10% of responding schools expose preservice students to any great extent, not surprising given other reports that confirm the sparse and disconnected nature in which technology of any sort is used by colleges of education (Barksdale 1996). Bednarz and Audet (1999) predicted that inservice professional development will remain the major means for introducing GIS into the curriculum. This will impede the implementation of GIS because of the time limits imposed on inservice teachers who are trying to acquire GIS skills.

Types of GIS Education

Sui (1995) and Thompson (1987) categorized GIS education into teaching *about* GIS and teaching *with* GIS. Teaching *about* GIS implies that the technology is peripheral to intellectual cores of geography and other disciplines, and therefore is taught as a technical field with a collection of marketable skills. Others who teach about GIS concentrate on theoretical foundations of GIS technology to expand the potential of the tool within and beyond the discipline of geographic information science (Goodchild 1992). Teaching *with* GIS stresses geographic concepts and using the tool to solve geographic problems in a variety of disciplines. GIS is seen not as an end in itself, but a means to find the spatial patterns of geographic phenomena. The foundations of this distinction have roots in information literacy research—where the technology is either the object of instruction or the tool of instruction. Although this dissertation emphasizes teaching *with* GIS, some secondary teachers are teaching *about* GIS, and therefore must be included.

Despite a growth in literature about GIS education since 1990, there is no consensus about a consistent pedagogic framework for teaching with GIS or about GIS. An exception was Sui (1995) who attempted to use Berry's Geographic Matrix as a pedagogic tool to teach *about* and *with* GIS. The bulk of the literature concerns GIS education at the college level, and is focused on the implementation of a GIS program within an individual institution. Even the GIS Core Curriculum developed by the National Center for Geographic Information and Analysis in 1991 (Goodchild and Kemp 1992a)Xnow in its second edition on the InternetXis chiefly concerned with teaching *about* GIS, rather than *with* GIS.

Models of GIS Implementation

The only attempt found in the literature to model GIS implementation was Audet and Paris' (1997) model, which was based on a survey of 45 schools. Three major phases of initiation, development, and institutionalization were associated with different amounts of software acquisition, hardware acquisition, data development, professional development activity, and curriculum development. This model needs to be tested nationwide to inform researchers, trainers, data providers, and software developers.

The repeated mention of the same researchers' names thus far in this chapter indicates that this research is currently being conducted by a very small number of individuals in the fields of geography and education.

Despite the fact that research on GIS implementation is lacking, the research problems can be given a foundation in existing scholarship in educational reform in geography, diffusion of innovations, and instructional technology. By analyzing these, forces can be uncovered that led to the current situation of GIS in education.

Educational Reform in Geography

Research on educational reform in geography provides additional insight about GIS implementation in schools. Reformist movements shape and are shaped by technological considerations, and are a powerful influence on the attitudes of school district officials and teachers. The attitudes and background of teachers considering and implementing GIS are shaped by a 20-year-old reform movement in geography education.

Since the mid-1980s, geography in the United States has undergone both a renaissance (a period of marked improvement) and a reformation, well documented by several researchers (Stoltman 1992; Gregg and Leinhardt 1994; Hill 1994a). Gallup polls and media coverage decrying the lack of geographic knowledge by American students were followed by an influential report entitled *A Nation At Risk* (National Commission on Excellence in Education 1983). The report claimed that the state of education for a large proportion of citizens had sunk to such a level that it threatened the very future of the nation. The following shock waves in politics and education led to the publication of the *Guidelines for Geographic Education: Elementary and Secondary Schools* (Joint Committee on Geographic Education

1984) which identified five themes in geographyXlocation, place, human-environment interaction, movement, and regions. In 1994, the U.S. Congress passed the Goals 2000: Educate America Act. This bill (Public Law 103-227) named geography as one of the five core subjects, along with English, history, mathematics, and science, to receive special emphasis in American schools. The first national standards in geography (Geography Education Standards Project 1994) presented 18 content standards grouped under six essential elements of geography: (1) the world in spatial terms; (2) places and regions; (3) physical systems; (4) human systems; (5) environment and society; and (6) the uses of geography. These standards were entitled *Geography for Life*, reflecting the belief of an increasing number of educators that the study of geography fosters an essential, lifelong set of skills (Bednarz 1994). Other developments included an alliance network between universities and K-12 teachers in each state, sponsored by the National Geographic Society, the implementation of an annual Geography Awareness Week, and the formation of the Geographic Education National Implementation Project (GENIP). In 1997, the College Board approved geography as a subject for Advanced Placement (A.P.) testing during academic year 2000-2001. At no time since perhaps the 1890s has awareness and demand for geography education been so conspicuous.

The publication of the five themes and the national standards both declared loud and clear to the entire educational community: Geography is a scientific method of inquiry, asking *why* things are located where they are, and *how* those things influence people's lives. As Boehm (1997) summarized, the important messages were that geography cannot be memorized, and that geography has enormous practical use in everyday life. Bednarz and Bednarz (1995) stated that "the best way to learn geography is to do geography." Geography is not a body of content to memorize, but a way of approaching problems and seeing the world. This change in thinking about geography led to current interest in exploratory geographic tools, including GIS.

Castner (1992) argued that geography's main contributions to general education are the manipulation of images—the tools of graphic expression—and the critical thinking skills of analysis and synthesis. These are all served by the use of GIS. In the publication *Rediscovering Geography*, the National Research Council (1997) called for more research on problem-solving and the roles of geographic education in decision-making, including spatial decision support systems, which affirmed that a major goal of the discipline of geography was to improve geography education for all.

The current interest in the use of educational GIS must be seen in the context of today's renaissance and reformation in geography education. The history and development of geography education is a repetitive one, coming back repeatedly to the same purposeXto examine the best tools, materials, and methods for teaching. Sarah and Robert Bednarz (1992) went so far as to call the history of geography education as "lessons learned and relearned" and claim that "nothing is new." During its history, the subject has been taught largely as an exercise in rote memorization, followed by criticism and calls for reform. Each time geography has been taught without requiring higher-order thinking skills, the subject suffered a decline in the amount of teaching in K-12 schools. Ridgley's (1926) statements of 75 years ago could have been written today: geographic facts are only a part of geography; students learn as they apply their own efforts, and construct their own knowledge. In another example, the 1965 *UNESCO Source Book for Geography Teaching* (International Geographical Union, Commission on the Teaching of

Geography 1965) stated that the educational value of geography included the development of powers of observation, memory, imagination, judgement, and reasoning. This, too, could have been penned as part of today's calls for geographic reasoning.

The forces that have shaped geography education have been perceived educational shortcomings, dissatisfaction with the content and the methods by which geography has been taught at several times in the past, the social climate of the nation, educational reforms, and even the definitions that people have applied to the discipline. These forces affect the implementation of GIS when it takes place within the discipline of geography. Geography teachers using GIS typically do not receive much support, because geography is not perceived as complex by most administrators. Furthermore, geography teachers have not received much technical training for the same reason, which adversely affects their ability to institute GIS.

The preceding analysis suggests that the current renaissance in geography education is a consequence of broader educational reform. The main messages that geographers have given as to the importance of the discipline have not changed much. Thus, teachers, administrators, GIS marketers, and researchers have seized trends in educational reform to advocate GIS in education. These major trends will be examined in the following section.

Trends in Educational Reform Influencing GIS in Education

Technological Innovation

"Technology" means more than machines—it is the application of scientific principles to solve practical problems. It can be considered a "process; a systematic blend of people, materials, methods, and machines" (Ely et al. 1992).

Advances in computer software have made the computer come of age with regards to teaching: For the first time, students can use the computer to explore their world, rather than looking at rote facts displayed on a computer screen. Means (1994) classified educational technology into four categories of use. It can be used as a tutor, (such as television and computer-aided-instruction), used to explore (such as simulations and some computer-based laboratories), applied as a tool (such as spreadsheets and video editing equipment), and used to communicate (such as Internet tools and distance learning). Using this classification, GIS technology touches on all four.

Computers can motivate students, introduce variety, simultaneously provide practical business skills, and encourage active participation. Stonier and Conlin (1985: 29) went so far as to state:

> "Some see computer graphics, animation, and visualization as uniquely suited for geography. Others cite the interactiveness of the computer as a key feature, and others point to its versatility in modeling, problem-solving, communications, presentations, exploration, study aid, and catalyst."

Instructional technology, the field concerned with design and evaluation of processes and resources for learning, pays little attention to GIS, even in large compendia such as *Instructional Technology: Past, Present, and Future* (Anglin 1995). This could be because traditional educational technologies, such as drill-and-practice programs, were based on replicability and control, categories that GIS clearly does not fit. Traditional educational technologists may not know how to deal with GIS yet.

Over-reliance on traditional teaching techniques such as the use of lectures, textbooks, and laboratories are cited by many as the cause for geographic illiteracy. New methods of computer-based instruction and inquiry-oriented learning are widely advocated (such as Gold et al. 1991). Visualizing and modeling earth processes in their complexities can be done on the computer using spatial analysis.

Computer-based instruction advocates in the field of geography education counsel both caution and encouragement. One caution is that teachers should not exchange one form of time consuming, rote tasks for another. For example, the hours spent performing calculations or drawing maps by hand can simply be exchanged for learning the operating system, commands, or languages of statistical or GIS-based computer packages. When this occurs, only lower-level technical skills are being exercised.

Kerr (1991) pointed out that successful GIS education will need to answer several questions. First, how well does GIS fit into the existing pedagogy? Helping students solve problems, develop strategies, and defend their own ideas is recommended by the American Association for the Advancement of Science and the National Council of Teachers of Mathematics. But these organizations recognize that these methods represent a profound change for many teachers: "Incorporating guided inquiry into standard secondary school courses requires a fundamental shift in educational paradigm. Guided inquiry "entails fundamental changes not merely in technology, but in curriculum, in the social organization and management of the classroom, in teaching approach, and ultimately in basic beliefs about the nature of knowledge and the roles of teachers and learners" (Wiske and Houde 1988: 214).

Kerr's second question dealt with logistics. How can students collect data outside the classroom to input into a GIS when the class period is less than one hour long? His third question asks how well GIS fits into the existing curriculum, given the rigid time constraints of teachers to cover a specified amount of material each semester. His final question points to the need to clearly state what results are expected, and to specify how the results will be evaluated.

Sivin-Kachala and Bialo (1994) reviewed 133 research projects over five years, and found that technology can make a measurable difference in student achievement. Cuban (1999) found that seven out of 10 teachers use computers at home, but fewer than two of 10 are frequent users of computers in the classroom. He claimed that the reasons for the discrepancy were not the fault of the teachers, but a misunderstanding of what teachers must deal with each day. This included contradictory and shifting advice from experts over the last 20 years as to what to use computers for in the classroom, insufficient time to develop curriculum, the "inherent unreliability of the technology," and policymakers' disrespect for teachers' opinions.

Institutional Restructuring

Nellis (1994) asserted that changing geographic learning will require three agendas of reform: (1) an emerging consensus about learning and teaching of geography; (2) training well-integrated users of technology in geographic education; (3) restructuring the current curriculum. Means (1994) and the U.S. Department of Education (1993) argued that without educational reform, technology cannot be used effectively in the classroom. David (1994) went further by claiming that "decisions about purchases and uses of technology are typically driven by the question of how to improve the effectiveness of what schools are already doingXnot how to transform what schools do (p. 169). Teachers need to create a school environment fundamentally different from the one they experienced as students (Sheingold 1991). Similar to other technological innovations, GIS is best implemented in the context of educational reform. Schools need to provide extensive and ongoing technical, administrative, and equipment support in order to integrate GIS (Woronov 1994). However, little has been done to assess the influence of reform on the adoption of GIS technology, and the impact of GIS technology on educational reform.

In a study of factors influencing educational change, Berman and McLaughlin (1974) discovered that the most successful changes were ones that went through “mutual modification.” Here, both the innovation and the settings were changed in the course of implementation. Nearly ten years after the first personal computers appeared in education, the U.S. Office of Technology Assessment (1988) claimed that most elements of the instructional process had not changed.

Jonassen (1995) stressed that until conceptions of learning change, technology will continue to simply be a delivery vehicle, and not a tool to think with. As such, it will have little effect on education. When technology is viewed as a support for instructional goals, and not as an end in itself, then it is more attractive and has a better chance of succeeding. Educational institutions will need to transform themselves in order to reap the benefits of information technology (Massy and Zemsky 1995). Benefits include increasing access to information, easing the limits of time and space for learning activities, enabling self-paced learning, and empowering students to have greater control over the learning process.

A survey of the use of educational media in public schools revealed that although the number of videocassette recorders and computers in the schools has increased dramatically during the past decade, these media have had relatively little effect on the instructional practices that are employed (U.S. Office of Technology Assessment 1988). Despite innovations, public schools have relied largely on the same methods of approach throughout the century (Cuban 1988). Studies of specific sites that invested in technology with the goal of changing the school or the classroom found that the equipment sat in a closet or that teachers used the technology to do the same things they had always done (Oakes and Schneider 1984). Means (1994) argued that the state of *art* in computer instruction has gone beyond on-screen workbooks, but the state of *practice* has not. The majority of school reform efforts are proceeding without any appreciable contribution from technology. Recently, however, the use of Internet technology has been linked to changed teaching methods (Means et al. 1993; Salvador 1994). Effective use requires sufficient goals and guidance (Serim and Koch 1996).

Literature on innovation has illustrated the difficulty in making long-lasting improvements in a system from only gradual, piecemeal approaches (Heuston 1977; Cuban 1986). Rather, important improvements have usually resulted from major changes followed by gradual changes until "desired results are reached" (Reiser and Salisbury 1995). These authors have argued that instructional technology's role will increase only if the structure of schools changes. Restructuring has been linked to increasing "time on task," extending the amount and relevance of individual feedback to students, implementing performance-based systems, individual-paced instruction, peer-tutoring, and cooperative learning strategies (Cohen, Kulik, and Kulik 1982).

Computer innovations are much more likely to be adopted by teachers and schools when they do not require major changes in the structure of present organizations and curricula (Bork 1987; Hills 1987; and Sales 1990). Therein lies both the problem and the challenge with GIS in the curriculum—its complexities and approach *do* require major changes. But, it has been advocated that when major changes take place, technology can help reform schools for the better.

Constructivism

Several social and educational trends are responsible for the current interest in applying GIS to education (Audet 1994). Constructivism has emerged as the dominant learning theory upon which to build curriculum and instruction, including computer-based educational practice (Hedberg et al. 1994). The student's role in constructivism as worker and maker of meaning, and the teacher's role as mentor and facilitator of learning are providing some incentive to design GIS-based materials. Because students build on knowledge of several disciplines to arrive at an open-ended set of solutions, the use of GIS has been perceived as an excellent example of a constructivist approach to education. However, Hannafin and Freeman (1995) postulated that the school environment may favor implementation of objectivist-based software rather than software grounded in the constructivist perspective. This clearly would work against GIS.

GIS projects allow students to share experiences and perspectives with others, and practice transferring their skills and knowledge to new situations. Bednarz (1995) argued that constructivism provides the justification for the use of GIS. In geography, few hard-and-fast rules apply consistently over time. This makes the discipline most suitable for a flexible environment where knowledge is presented and learned in a variety of different ways and for different purposes. In a GIS environment, students construct knowledge through building databases and maps, explore spatial relationships, learn from real-world data and places, and guide themselves in their explorations.

Jonassen (1995) recommended that educational technology emphasize active, constructive, collaborative, intentional, conversational, contextualized, and reflective learning. Although these learning scenarios may be realized through GIS,

GIS is ignored even by research that presents practical methods of incorporating constructivism in the classroom (such as Brooks and Brooks 1993). Research describing technology's use in the social studies frequently mention video and Internet technology, but seldom GIS. *Social Education's* special 1998 issue dedicated to "Teaching in the Information Age" contained not one article that mentioned GIS. The 1999 technology issue also lacked a GIS content, although one article appeared about using satellite images from Radarsat Corporation (Kirman 1999). Simpler in concept than the use of a GIS, the Radarsat images and software were contained on one easy-to-use CD-ROM.

Standards Movement

The publication of national content standards has been an important influence on the spread of teaching with GIS in the secondary curriculum. GIS is mentioned in an appendix to the national geography standards. A more important influence on GIS is the emphasis throughout the geography standards on *doing* geography equipped with geographic skills rather than *knowing* geographic facts. Similarly, the national science standards emphasize inquiry and investigation (National Research Council 1996). The national educational technology standards (International Society for Technology in Education 2000) stress integrative uses of technology for communication, research, and evaluation, and for solving real-world problems. Instructors and school district administrators use local, state, and national standards to justify the implementation of GIS (Ramirez 1995). Since GIS is multidisciplinary technology tool, many teachers find that they can integrate the standards if they also integrate GIS.

Integrated, Authentic Practice

Educational reform stresses cooperative or team learning and project-based, open-ended learning. The concept of "authentic practice" is finding a voice in geography teaching, as real-world contexts for learning become more common. Projects such as Activities and Readings in the Geography of the World (ARGWorld) from the Association of American Geographers, and Mission Geography from GENIP both emphasize "doing geography" rather than reading *about* geography. Interest in GIS as an applied tool increases as it is recognized as a technique and tool for *doing* geography. Furthermore, integrated, interdisciplinary approaches to curriculum development naturally find a home in geography teaching. Geographers "tend to look at issues holistically, and the value of this broad perspective…is gaining more acceptance" (Bednarz and Petersen 1994: 3). Real problems, as opposed to academic problems, involve gathering information, analyzing all relevant information, and identifying satisfactory outcomes from among several possible solutions (Kohn 1982). These are also termed "performance-oriented tasks" to solve "messy dilemmas," suitable for GIS because it *is* a problem-solving tool for real-world data.

School-to-Career Movement

The movement to equip students with the skills necessary to excel in the workplace has a long history in the American school system. School-to-career programs receive federal funding from the School to Work Opportunity Act of 1994 (Knight 1999) and receive media attention to the present day (Nelson 1999). GIS has not been frequently mentioned in the literature by those seeking to expand vocational training beyond such traditional skills as auto mechanics and cosmetology. However, as GIS functions become attached to more commonly used software (such as spreadsheets) and careers (such as business marketing), it is increasingly recognized as an important addition for school-to-career programs. Proponents point to expanding and steady employment opportunities for those skilled in GIS. Some schools are now providing GIS services to city government (Environmental Systems Research Institute 1995 and 1997).

School-to-Community Linkage

GIS has been advocated as a means to link schools with their communities. Alibrandi (1998) stated that "because GIS is generally a municipally-owned tool used for planning and development, teachers using GIS have integrated education with community problem-solving." Promotional literature in geography with titles such as "The Complex Issues Facing Your Community and Business Require Geographic Knowledge" (National Council for Geographic Education 1997) is widespread and is cited as justification for incorporating GIS-based methods.

Authentic Assessment

Growing dissatisfaction with current standardized tests is causing emphasis on alternative, authentic performance assessments (Darling-Hammond 1994; Archbald and Newman 1988). Authentic assessments are any evaluation that simulates how workers are evaluated on the job, such as from a oral and written presentation or a portfolio that highlights work done during the semester. Some educators are now considering alternative forms of "teaching to" these assessments, including open-ended exploratory tools such as GIS. A student's final GIS project results could fit the model of an alternative assessment, because the student could be creative within certain parameters to create an oral presentation and a written portfolio of text, maps, images, and charts, from in-class work and field work.

Active, Student-Centered Learning

Student-centered learning requires a change from students as passive receivers of knowledge to becoming explorers of existing knowledge and creators of their own knowledge (Silberman 1996; Harmin 1994). According to proponents of student-centered learning, learning should be an open-ended process that includes critical reflection (Moser and Hanson 1996). Active learning transforms the subject being learned. For example, geography students do not merely learn more and more geography, but in so doing, they extend and transform what geography is.

Active learning, where a student learns a content area by *doing*, not simply reading about what others do, is increasingly used as a model for GIS-based learning. For example, through the NSF-sponsored "GIS Access" project, teachers at all levels across the country are trained not only in GIS techniques, but also in active learning theory (Doak 1999; GIS Access 1999). The goal of tying this pedagogical theory to GIS training is to provide a reformist context for the technology, and thereby increase the likelihood that it will "take hold."

Globalization and Educational Accountability

Hill (1995a) identified two trends that will affect geography education in the future. The first is that there will be a demand for a new, more rigorous kind of education to prepare students to work in a world of increasing globalization. Some claim that through spatial analysis, GIS-based education can meet this goal. It may also meet the second trend Hill identifiedXincreased demand from the public that education be accountable for preparing students with adequate skills for the workplace. Gerber (1992) stated that “if geographical education is truly intended to prepare students for lifelong education, then it should contain learning experiences that do that, including the impact of technology” (p. 297). Associated with more teaching about the interconnectedness of physical and human systems is an increasing amount of environmental education. Some of these teachers are turning to GIS, since GIS began in the field of natural resources and can be used to model the earth as a system. A study of environment-based teaching methods demonstrated improved student and teacher performance in 40 schools across the country (Lieberman and Hoody 1999).

Inquiry

Hill (1995a) defined an inquiry-oriented method as that which “poses questions and proposes answers about the real world and tests its answers with real data” (p. 48). This “doing real geography” approach leads to meaning and understanding. Students answer questions of geographic significance by analyzing and evaluating data, using their developing geographic methods and skills (Hill 1993). Geography then “makes sense not as a heap of isolated facts, but as a network of ideas and procedures” (Slater 1993: 60). The student identifies questions to reach generalizations through data processing and interpretation. Computer technology may facilitate the teaching and learning of these skills. A related inquiry-based model for GIS in education is the problem-based approach. The problem-based approach places students in the active role of problem solvers confronted with an ill-structured problem that mirrors real-world situations (Finkle and Torp 1995). Students need more information than is initially presented to them, there is no fixed formula or “right way” to investigate, the problem changes as information is found, and there may be no single “right” answer (Stepien et al. 1993).

Information Literacy

Defined by the American Library Association Presidential Committee on Information Literacy (1989), information literacy refers to a person’s ability to recognize when information is needed, and the person has the ability to locate, evaluate, and use effectively the needed information. Three themes predominate in research: Information literacy is a process, it must be integrated with the curriculum, and information literacy skills are vital to future success (Plotnick 1999; Breivik and Senn 1998; Spitzer et al. 1998). Because the use, conversion, and format of attribute and spatial data are keys to every application of GIS, the tool is cited as integral for building information literacy in students (see Barron 1995).

These trends and models identified above have set the stage for the implementation of GIS. The diffusion of innovations model provides one method of examining *how* GIS implementation is taking place.

Diffusion of Innovations

Rogers’ (1995) research on the diffusions of innovations provides a useful model for evaluating the spread of GIS implementation at the secondary level. Diffusion is defined as the “process by which an innovation is communicated through certain channels over time among members of a social system” (p. 5). An innovation is an “idea, practice, or object that is perceived as new by an individual or other unit of adoption” (p. 11). This model emphasizes uncertainty regarding the consequences of adoption of the innovation, the importance of communications to provide information about the advantages and disadvantages of an innovation, and the dependency of speed and extent of diffusion on political and social processes, not simply the technical worth of the product. GIS has been spreading, or "diffusing," through society since its inception during the 1960s. Research in GIS as a tool began in universities but not until the 1990s did it begin to influence K-12 education.

Campbell (1996) identified three theories that explain why a new technology will diffuse: Technological determinism, economic determinism, and social interaction. Technological determinism asserts that an innovation will inevitably diffuse because of its perceived inherent advantages. For example, if someone develops better software, it is bound to spread. In the context of GIS in education, this theory is immediately suspect. If GIS is perceived to have so many advantages for education, why has its diffusion been so fragmented and slow? Economic determinism means that technologies diffuse because people perceive them to be an essential part of economic growth. Conversely, economic growth is dependent upon technological innovation. This theory is also suspect because economic growth has not guaranteed the diffusion of GIS through secondary education, despite its adoption by business and government because of its economic advantages. Social interactionism assumes that technology is socially constructed, so innovations are diffused from the interaction of technology and users in organizational contexts. Because schools are social institutions, this theory is the most applicable to education. An example of this theory's application is Nedovic-Budic's (1998) framework for determining the likelihood that an individual would become a GIS user. Personal characteristics, attitude, and background influence if and how GIS will be used. This dissertation examines these three theories to determine if teachers decide to use GIS primarily because they perceive a technological or economic benefit, or if their style and attitudes are more important. Indeed, Powell's (1999) research indicates that implementation will occur only if teachers' beliefs are aligned with the philosophy of the innovative teaching method or materials.

Despite the spread of GIS to business, government, and academia in less than 30 years, research on GIS diffusion is still in its infancy. Masser and Onsrud (1993) and Masser, Campbell, and Craglia (1996) researched the spread of GIS, but they emphasized the diffusion of GIS in European local government.

Clarke (1990) offered three stages in the adaptation of a new technology: reluctance, replication, and full implementation. Replication refers to the use of technology in the same manner as the previous technology. This dissertation examines these stages using GIS as the new technology.

The implementation of GIS is affected by several important social and educational trends, and has been diffusing slowly through the educational system. The next section addresses the most important challenges to this diffusion.

Challenges in the Implementation of GIS in Secondary Education

Introduction

As a computer tool, educators who implement GIS share many of the challenges that face implementers of other computer technologies, such as scarce teacher inservice and preservice training, poor equipment, and insufficient access to equipment (Parker 1999). However, few studies directly address the challenges to GIS implementation. Whereas research abounds concerning the potential catalysts, advantages, and challenges to Internet technology in education (Rudenstine 1997; Bailey and Cotler 1994), similar research on GIS in education is lacking. This demarcates the relative difficulty between the two: Internet technology has become mainstreamed partly because it requires little time to implement, unlike GIS.

Structural Challenges

Only a small number of studies address challenges to GIS implementation. No articles on the difficulties or failed attempts to incorporate GIS, whether in schools or in any other organization, were found in newsletters and journals from professional GIS societies, conference proceedings, or software companies. Geographers have provided most of the challenge research. Barriers to GIS adoption in Ontario included limited access to hardware and software, insufficient preservice and inservice training, and the paucity of appropriate teaching resources (Crechiolo 1997). Educators lacked clear guidelines that apply GIS functionality to the teaching of geographic concepts and skills at the pre-collegiate level. Wardley's (1997) study of southwestern Michigan high school students found that although only 37% of schools lacked computers, 58% of *the social studies students did not have access* to computers. Donaldson (2000) found adequate computer stock and funding in 750 Ohio high schools, but a lack of GIS awareness; subsequently, GIS was used by only 3% of teachers surveyed. These few studies, while offering some regionally-based data, do not provide sufficient understanding of the structural and pedagogical issues affecting the incorporation of GIS in geography on a national scale.

Eason (1993) identified organizational mismatch, negative user acceptability, and limitations and difficulties with the software as three reasons for failure to adopt GIS technology. Barriers to implementing GIS in education include those inherent to the incorporation of other computer technologyXaccess to the hardware, time needed to gain proficiency, lack of confidence and expertise, and the suitability of software (Kent 1992). “Often, states will spend millions on equipment, and may only spend a fraction—2 or 3 percent—on training. If you’re not training, you’re throwing money away” (Zehr 1997: 24). Implementing GIS adds additional challenges: pedagogical method, school support, teacher training, attitudes, class structure, school district requirements, and demonstrated and perceived effectiveness of the benefits of GIS. No national survey or study was found that examined barriers and catalysts that can hinder or encourage the educational implementation of GIS.

Challenges Discovered Via Implementation Surveys

Two comprehensive surveys including GIS in education were found. One is a survey of 6,000 post-secondary institutions using GIS around the world, conducted several times since 1985 (Morgan et al. 1996). The attempt to include the K-12 community for the 1998 survey reflects the interest and growth in GIS education and the more recent interest in GIS in primary and secondary education. The survey’s emphasis was limited to the hardware and software used by survey respondents. Another survey surveyed 193 high school and university educators throughout the world to address their understanding of and attitudes about geographic technology (Gerber 1992). It revealed that just 32.6% of educators could use GIS software, compared to 84.8% who could use a computer, and 83.3% who could use word processing software. The only software used often less than GIS was remote sensing software. The fact that 56.5% had *knowledge* of GIS software but only 32.6% could *use* it implies that GIS is more complex than other software.

Challenges Within the Classroom

Studies of the use of technology in education repeatedly identify the need for teacher training in technology. The report *Linking for Learning* (U.S. Office of Technology Assessment 1989) made this need evident a decade ago. The dichotomy between teachers and businesspeople is clear: Businesses spend millions on GIS training each year for their employees, but teachers, using the same technological tool, receive little formal training. Some evidence that technology is causing a restructuring of education can be seen in the establishment of regional technology centers by the U.S. Department of Education in 1995.

Integrating GIS into classroom practice is a complex process. Teachers must match the computers and the software with instructional goals, the subject matter, the students themselves, and the context of instruction (Winkler et al. 1985). Kerr stated that it is necessary to understand "how teachers learn not only to use computers, but also to integrate them into the curriculum and the flow of classroom activities" (1991: 122). Fitzpatrick (1997b) suggested that science teachers are more inclined than geography teachers to be willing to use an exploratory tool in which the outcomes are uncertain. Few studies have examined the integration of GIS into the curriculum, or the change in meaning and dynamics in both teaching and learning that occurs in classrooms using GIS.

Geography's diverse subject matter lends itself well to many teaching techniques, from field studies, resource-based learning, lecture, to media-based learning. Still, teaching methods that use debate, student presentations, discussions, role-playing, games, and simulations have been slower to take hold than those using traditional techniques. One reason is because both the students and the instructor have to undergo a paradigm shift in their goals and expectations to help them take root. Using GIS tools forces the same shift. For example, teachers want to make sure that students will learn once they begin using exploratory data analysis, which does not lend itself well to a traditional worksheet or test.

Despite all that is written about the affordability of today's computing equipment, the fact remains that an effective GIS program requires an entire computer laboratory. These labs usually require more robust equipment than that which presently exists in most school laboratories. Schools and school districts have difficulty purchasing costly items that have not been proven to increase content learned. The cost is partly the result of the need for large computer monitors to effectively view spatial data. Adding to the cost is sufficient memory, at least 32 megabytes, to handle huge images and databases.

Another reason for the slow pace of the GIS advance in secondary education is that large amounts of time must be invested by teachers to implement the technology. By its very nature, GIS is an open-ended tool that requires input from the user; it is not a preprogrammed set of exercises that have been computerized. It is not an atlas on a computer, but a spatial data explorer with few limitations in functionality. Similar to a word processor that opens with an empty screen, awaiting user input, GIS software opens with a blank template or a menu. It is up to the student to tell the system what he or she wishes to examine, find the data, manipulate the data, and present the data in an understandable format. Before this can happen, however, the *teacher* has to at least know the essentials about navigating the software. Otherwise, only the most computer-literate and inquisitive students will have the patience to learn it. Despite advances in the ease-of-use of GIS, interfaces are still cumbersome and less than intuitive (Walsh 1992).

After the software has been mastered sufficiently to at least allow for some geographic inquiry, students and teachers must understand related computer software and hardware to take full advantage of the capabilities of a GIS. A particularly significant issue in GIS implementation is that it is by definition a *system*. Learning a system means to understand related computer functions such as downloading, analyzing, manipulating, archiving, and plotting data. Some of these functions take place outside of the GIS, inside such programs as desktop publishing programs, remote sensing programs, image manipulation programs, spreadsheets, statistics packages, and word processors. GIS use also takes advantage of hardware such as scanners, digitizers, printers, and plotters. In a survey of 898 schools, almost half of the teachers reported that they needed technical support at least once a month. More significantly, of these, more than two-thirds said the support was not available when they needed it. For almost half of those who needed technical help, it was only available "sometimes" (Center for Research on Information Technology and Organizations 1999).

Another reason for the slow adoption of GIS is that time is needed to locate, acquire, create, test, and implement software and instructional modules once the system software and hardware is learned. Hill (1994b) articulated the need for developing instructional materials in geography and to train teachers in their use. This dissertation seeks to help meet these needs by developing lesson modules that teachers can use in their classroom.

Teachers lack the awareness of the educational potential of GIS. School principals and superintendents, who will ultimately have to decide whether to support these endeavors, may be even less aware of the technology than are teachers. Both groups lack the training essential to use GIS. Training materials need to be generated both in written form and as tutorials using the actual GIS software that teachers may purchase. Perhaps even more important than training is support. Educational researchers agree that support is an essential factor in school change: "The more factors supporting implementation, the more change in practice will be accomplished" (Fullan and Steigelbauer 1991: 67). Cox summarized the scope of support necessary:

> "Our findings suggest that school improvement efforts need support at two levels: assistance focused on the *content* of new practice, directed at the teachers who are implementing the innovation; and assistance focused on the *context* of the new practice, aimed at securing the necessary approval, resources, facilities, and personnel to ensure continuation and institutionalization of the innovation" (1983: 13).

Although advances have been made in increased availability and types of digital spatial data, teachers need to understand the location, variety, scales, quality, and formats of the data. GIS professionals understand that the accuracy of any map created with a GIS is a product of decisions and compromises on cost, effort, and data availability (Bernhardsen 1992). Teachers, however, may not have the background on which to base these kinds of decisions, and thereby underestimate the difficulty of gathering data and creating maps (Woronov 1994).

Guidance and Foundations

Studies on Internet technology have shown that without sufficient goals and guidance, students use the tools as entertainment or to simply fill time. This random browsing may familiarize them with the tools, but not with the process of research or with the subject matter for which the tool is being used. Similar concerns have been voiced with GIS, particularly if the goal is to use it to teach a content area. The difference between random clicking and a goal-focused method is that the latter becomes pointed inquiry with an educational purpose.

One such purpose in using GIS in geography is that students can learn to identify the different types, quality, scale, and purposes of spatial data. They must then understand how to bring the data from a textual reference or from the Internet into the GIS to bear on their problem. Thus, the challenge of using GIS tools is not the difficulty of the use of the tools, because the tools are relatively easy for most students to grasp. The challenge lies in using the tools to learn geographic content. Finding the data is not an end in itself. The data must be analyzed spatially so that it can be interpreted. A GIS may be the ideal tool to perform spatial analysis because students can choose and create their own data set, import it from another source, choose the area of study, choose the scale of study, and choose which data are important to solve the problem.

A tangled issue lies at the foundation of all the abovementioned implementation concerns. GIS can be used to teach geographic content, but students also may need to understand the geographic concepts that underlie the systems. Walsh (1992) argues that "to know GIS one must first know geography." Participants in the Geography Education Standards Project, after acknowledging the power of GIS, stated that to use the technology "requires competence in geography itself" (Geography Education Standards Project 1994: 256). To illustrate these points, Audet, Huxhold, and Ramasubramanian (1993) completed a study of high school GIS. At the outset, they assumed that students had the ability to recognize real-life spatial problems and possessed the skills needed to solve them. They found that students worked well with paper maps, a restricted data set, and well-defined questions. But when asked to recognize spatial patterns in geographic data, the students attempted to solve the problem by “conducting an untargeted browse through the database”. Students could not formulate and resolve spatial problems. Because teachers have had limited training and therefore little ability to do spatial analysis, their ability to use GIS will be severely curtailed (Bednarz and Ludwig 1997).

With so many challenges to the implementation of GIS, what makes teachers want to implement this technology? The next section will examine the literature that describes the potential of GIS in education—some of which has already been realized, and some of which has yet to be attempted.

The Potential of GIS in Secondary Education

A small but growing number of research studies and application reports from both geographers and non-geographers, educators and non-educators, cite the potential contribution of GIS to education. The use of GIS in geography education has great potential to enhance geographic analysis and creative thinking (King 1991; White and Simms 1993). GIS, because of its suitability for constructivist, inquiry-oriented methods of analysis, has great potential as a tool to aid the acquisition of standards-based knowledge and skills. Bednarz (1995) illustrated the clear linkages between GIS and constructivist learning: Students construct knowledge through building databases and maps, and explore spatial relationships through mapping. Hill (1995b) identified technology as “clearly within the scope of issues-based geographic inquiry.” Projects based on GIS technology require students in groups to identify resources, gather data, and test data and hypotheses.

Perhaps most importantly, mention of GIS in the national geography standards placed GIS in the forefront of the minds of many practitioners who seek to reform geography education. “Geographic information systems make the process of presenting and analyzing geographic information easier, so they accelerate geographic inquiry” stated the participants of the Geography Education Standards Project (1994: 45). They also stated that “the power of a GIS is that it allows us to ask questions of data” (p. 256). A recent survey reported that 59% of teachers give the software in their classrooms a C or lower when it comes to matching with state and district tests (Education Week 1999). Teachers want software that will allow students to develop standards-based skills, and GIS is viewed by some as having the potential to do so.

Even in non-educational applications such as natural resource management, GIS is hailed as “the great integrator.” GIS technology offers the ability to help identify the interconnections of isolated sets of facts or observations, providing a holistic understanding of the earth’s surface (Maynard 1991). This characteristic appeals to many educators looking for tools to break down barriers between disciplines. Numerous studies disparage fragmented teaching (Boyer 1983) that only emphasizes some ways of learning and not others (Goodlad 1984). Survey results have demonstrated that environmental issues are important to young learners (Audet 1994), and GIS has allowed students to study issues of local and global concern.

GIS has been advocated by some educators as helping students develop thinking skills, such as visualization, data analysis, and problem solving, accessing and exploring geographical data, investigating real-world problems at many scales, developing technological literacy, and preparing for employment. These advocates state that because information can be seen graphically and visually, rather than in tabular form, more learning will take place (Tufte 1990; Gerber 1995). Research in learning styles suggests that many learners are visually-oriented, which is conducive to GIS. GIS has been praised because it allows students to study local issues with local data (Carlstrom and Quinlan 1997) and because it promotes students' "sense of place" (Sanger 1997).

Researchers point to a mismatch between what education provides and what society and businesses need (for example, Oblinger and Maruyama 1996). Forman (1995: 23) outlined these mismatches as follows:

Table 2.1. Mismatches Between Educational Goals and Business Requirements. Adapted from Forman (1995: 23).

Educational Orientation	Business Requirements
Facts	Problem Solving
Individual Effort	Team Skills
Passing a Test	Learning How to Learn
Achieving a Grade	Continuous Improvement
Individual Courses	Interdisciplinary Knowledge
Receiving Information	Interacting with and Processing Information
Technology Separate from Learning	Technology Integral to Learning

GIS has been cited as one of the technologies essential to the world of work. Basing their arguments on the U.S. Secretary of Labor's Commission on Achieving Necessary Skills (U.S. Department of Labor 1991), advocates (such as Hill 1995a and Downs 1994b) have linked GIS to the five competencies identified as essential for future work success. These include the ability to work with resources, with others, with information, with technology, and ability to understand systems. Since

GIS is by definition a technological information system, its proponents state that it can help provide students with lifelong work skills.

McNally (1987) called for techniques for teaching geography in a relevant and effective manner, stating that GIS allows students not only to learn about geography, but GIS also familiarizes them with an essential tool of the discipline. Clark (1989) advocated information technology in geography because it allows for hitherto unrecognizable patterns to emerge.

GIS in education has been linked to Pattison's (1964) four traditions in geography—spatial, area, human-environment interaction, and earth science (Mark and Dickinson 1991; Sui 1995). Goodchild and Kemp at the NCGIA (1992b) were early advocates for the spread of GIS beyond college-level teaching to secondary education. The reasons cited were the increasing importance of GIS in the workplace and in environmental analysis, and for motivating student interest in geography and science. Fitzpatrick (1990) summarized geographic software into three categories at the beginning of the decade: Exploratory, simulation, and database. Since that time, the rise of desktop GIS has incorporated the exploratory and database functions. Most who point to GIS cite geographic analysis as its chief benefit (King 1991).

GIS has been shown to be suitable for young students (Fitzpatrick 1997a). Other studies document the utility of GIS at specific schools (Environmental Systems Research Institute 1998c; Fazio and Keranen 1995; Hamilton and Paul 1997; Ramirez 1996; Trotter 1998; Williams 1997), such as where students won a presidential award (McGarigle 1997a). Studies have summarized the applications and benefits of GIS (Keranen 1996; Walker et al. 2000) and document the viability of teaching geography with computers (Fitzpatrick 1993). Another study illustrating how elementary school students chose freeway routes in the Salt Lake valley has been cited as evidence that GIS promotes higher-order thinking skills and connectedness to the community (Robison 1996). The evidence stemmed from the fact that the author documented his work in a national GIS trade magazine while he was a 12-year-old student, and because the class presented their findings to the Utah Transit Authority.

Students and teachers have begun to use GIS to explore their environment, to better understand key concepts in numerous social and physical sciences. The interactive nature of the technology enables students to actively explore their own maps and data, rather than simply looking at maps in a textbook. At Thomas Jefferson High School for Science and Technology in Virginia, students map and study not only their local area, but also the 1988 fires of Yellowstone, the 1992 oil fires of Kuwait, and the 1993 Mississippi flood (McGarigle 1997b). The Urban Environmental Education Program of Detroit helps urban, disadvantaged students better understand their environment through the use of GIS to map their city's resources. Two students at Detroit's Cass Technical High School received presidential recognition and helped the City of Detroit win $100 million in federal grants by helping designate an area of the city as an urban empowerment zone (Environmental Systems Research Institute 1995). Because of their work on mapping homes with lead pipe, the school received $1.67 million to investigate additional health problems in Detroit. Ford Motor Company asked these students to use GIS to conduct a demographic analysis of auto markets in India, Brazil, and China (Braus 1999). Students at Olathe High School, Kansas, collaborate with their peers around the country, tagging and monitoring the flight of thousands of Monarch butterflies. Students at University School in Hunting Valley, Ohio, study a local lake and its watershed by analyzing field-collected geologic, hydrologic, biologic, and atmospheric observations within a GIS.

All of these studies have one of two goals in common. They either cite the *potential* of GIS in education, or they cite *anecdotal examples* of how GIS has worked in a small number of schools. No study has examined the actual practice of GIS in education at a national scale, and only a few studies have evaluated the difference that learning with GIS makes on geographic skills, professional development, or pedagogical methods. The only study found on curricular GIS implementation was at the college level (Hamilton et al. 1995).

Given this body of literature on GIS challenges and its potential, the next section will review the literature on the current state of GIS in secondary education, including historical forces that brought it to this point.

The Advancement of GIS in Secondary Education.

A variety of organizations, conferences, individuals, institutions, forces, and projects have combined to foster the progress of GIS in primary and secondary education. The literature indicates that it is implemented primarily in the science curriculum, but also in the social studies, particularly geography and history. One reason for the spread of technological tools into geography instruction is that more organizations are becoming involved with technology in geography education than in the past.

Professional Societies

Professional societies of educators and GIS practitioners are increasingly active in educational GIS. Members of state GIS user groups provide training and data and develop GIS tools for educators, such Montana's GIS-based exploration of Lewis and Clark (Zentz 1999). The National Council for Geographic Education (NCGE) and the National Geographic Society (NGS) sponsored the first National GIS Teacher Training Institute during July 1998. Earthwatch Institute sponsors Student Challenge Awards Programs in which college students and faculty work with selected high-school students on scientific research, using GIS and other technological tools (Queen et al. 1998).

National GIS conferences sponsored by professional societies began including an educational track for workshops and papers on research in GIS education in the early 1990s. These tracks began with how to design university GIS programs but have expanded to include research into issues surrounding implementing GIS in a school district or a single school at the primary and secondary level. The annual meeting of URISA, the ESRI user conference, Geographic Information Systems / Land Information Systems (GIS/LIS), the Geospatial Information Technology Association (GITA), and the conference of the American Society for Photogrammetry and Remote Sensing (ASPRS) have begun soliciting these research papers for their "education tracks." In addition, they have begun to include educational GIS technical sessions and even hold workshops for primary and secondary students. "SIT-UPPS" ("Spatialists" in Information Technology: URISA's Program for Student Studies) at the URISA conferences during the mid-1990s was a notable example, where children of conference participants were trained in GIS for one weekend. These students displayed their work in exhibit halls alongside that of GIS professionals. Nevertheless, literature from these conferences (such as Hamilton et al. 1995) emphasized anecdotal histories of the development of GIS in college programs. Furthermore, nearly all GIS instruction analyzed was to teach GIS, not to teach a content area *using* GIS.

Universities

Universities are increasingly involved in secondary geography education, particularly due to the network of state geography alliances established in universities in 1986 by the National Geographic Society. Over a decade ago, Walsh (1988) advocated using GIS in primary and secondary schools. GIS is included in an increasing number of geography institutes for teachers, such as eight workshops during Winter 2000 sponsored by the Illinois Geographic Alliance, NGS, ESRI, the Population Reference Bureau, Northeastern Illinois University, the Social Science Data Analysis Network, and the Northside College Preparatory School of Chicago. The University of California-Santa Barbara's National Center for Geographic Information and Analysis (NCGIA) began a Secondary Education Project and found increasing national support (Palladino 1992 and 1994). Two educational modules based on *Idrisi* and *ArcView* were distributed (Palladino 1998). The NCGIA makes other disciplines aware of the geography embedded within them, and is responsible for spreading geographic technologies into other social sciences.

A "GIS In the Schools" workshop held in July 1992 (Palladino 1992) was followed by the first conference on educational GIS in 1994 (Barstow et al. 1994). This conference continued in 1996 and 1999 as EDGIS II and EDGIS III. Three international symposia on GIS in Higher Education were sponsored by ESRI, Intergraph, the UCGIS, and NCGE in 1995 and 1996, which expanded to the K-12 sector by 1998. These conferences created a national dialogue on research needs and implementation strategies, continued largely via an Internet listserve sponsored by the Technological Education Research Council (TERC).

An environmental education project involving the Palm Beach County GIS, between Florida Atlantic University and Jupiter Community High School (Ramirez and Althouse 1995) illustrates an increasing number of partnerships among universities, communities, and government agencies. A statewide initiative that incorporates Internet and GIS into Grade 6 through 12 curricula was initiated by the University of Wyoming (McClurg and Lerner 1998). A partnership among Colorado State University and the Poudre School District brought training, software, and hardware to schools throughout the district (Laituri and Linn 1999). Organizers of a new masters degree program in integrated science education through the University of Colorado-Denver chose GIS as a key component for enrolled inservice and preservice teachers.

Private Companies

Commercial GIS vendors have also provided an important impetus to the spread of GIS in secondary education. By offering discounts on their software to schools, providing training, and encouraging partnerships between schools and professional GIS users (Bednarz 1995), commercial GIS vendors encourage the use of their own software, but also the use of geographic technology in general. As far back as 1991, IBM and the National Geographic Society sponsored two summer Educational Technology Leadership Institutes, which spawned several state-level institutes for teachers. By May 1993, these 64 teachers had conducted 589 workshops, affecting 19,200 educators (Miller and Zeigler 1994). Since 1994, GTE has funded "Gtech"Xa technology project for mathematics and science in Texas schools through Texas A&M University (Texas Center for Educational Technology 1998).

Examples of the influence of commercial GIS vendors abound. The MapInfo Corporation announced during 1996 that their *MapInfo* software as well as compatible data sets would be available for 75% off the regular price for schools. Intergraph began offering free copies of *GeoMedia* software to schools during 1999. The Environmental Systems Research Institute, producers of *ArcView* GIS, maintains an active national education outreach staff, marketing the software specifically to schools and libraries at a greatly reduced rate from that paid by the general public. The geography laboratories at Clark University announced a school and library packet of their *Idrisi* software at 70% off the usual price during the Fall of 1995. Moreover, the prices for *ArcView* and *Idrisi* include a site license, critical for a school seeking to establish a spatial data laboratory with multiple computers.

Government Agencies

Government agencies are partnering with schools, sponsoring educational technology training for students and teachers. Government agencies that are active in the production and application of spatial digital data have been increasing their emphasis on outreach for three reasons. First, many of these agencies face smaller budgets and threatened cuts, but increased demand for their products and services. Educational outreach is becoming one method of demonstrating the relevance of their programs. For example, local governments in southeastern Wisconsin developed a land use plan involving educators, students, and businesses (URISA News 1998). Second, these agencies are also increasing their emphasis on cooperative agreements with professional societies, other organizations, and other government agencies to acquire critically-needed funds. A key organization is the Federal Geographic Data Committee (FGDC), an interagency group that promotes the coordinated development, use, and sharing of geospatial data. One of the FGDC's contributions to educational GIS is through funding educational projects that involve the use of digital geospatial data through the "Community-Federal Information Partnership." By late 1999, this partnership had totaled $644,623 in grant support (Federal Geographic Data Committee 1999). The FGDC's "community demonstration projects," funded by USGS, Department of Justice, EPA, NOAA, the USDA, and the BLM, seeks to show how a cross-government, cross-functional geospatial data and applications can be used to solve the problems faced by a community. Schools are a major component sought in these demonstration projects.

Third, government agencies now are taking responsibility to educate their data users. An example is GEODESY, funded through NASA's Mississippi Space Commerce Educational Outreach Program, used in 86 middle and high school technology preparation laboratories in the state of Mississippi (Radke 1999).

Research Groups

Increasing support for GIS comes from nontraditional research groups, who receive funding from government, private, and academic sources. The most active are the Center for Image Processing in Education (CIPE) in Tucson, Arizona, the Berkeley Geo-Research Group in California, the Technological Education Research Center (TERC), the Education Development Center of Newton, Massachusetts, and the five-state Upper Midwest Aerospace Consortium (UMAC) from the University of

North Dakota. These organizations conduct research in educational GIS, provide training, and create lesson modules.

Advances in Data

The rapid expansion of the GIS industry in the 1980s could not have occurred without the availability of large digital spatial databases produced by government agencies. Since 1994, the Federal Geographic Data Committee has been promoting the concept of the National Spatial Data Infrastructure (NSDI), a body of spatial data, standards, and metadataXinformation about the data's origins. Thompson (1997) prepared a guide to the NSDI for geography teachers.

Not only has more data become available, but it is available in ways that more educators can use. For example, rather than the standard 9-track tape of five years ago, most digital data is available on CD-ROM, 8mm tape, or on file transfer protocol (FTP) Internet sites. GeoLytics, for example, produces a single CD-ROM with census data for all 7 million US blocks. The ease of obtaining ready-made spatial base data for the desired study area at the correct scale and resolution for a GIS project is critical, since the initial cost of building the data base is commonly five to ten times the cost of hardware and software. Data gathering typically represents 75% of the total GIS expenditure for a project (Aronoff 1991). This situation is amplified for educators, who can seldom afford to construct their own base data. Having a wide range of data sources enables diverse curricular applications of GIS.

Most spatial data must be manipulated before it can be used in a GIS. Progress has been made in this area as well, with more governments and private companies providing data translators and viewers. Government agencies have also spearheaded efforts for common digital data standards to reduce the plethora of formats, such as the Spatial Data Transfer Standard, and have devised an expanded, standardized set of metadata that fully describes the origin, vintage, and resolution of each data set. At first, these efforts were met with resistance from private companies, who feared that they would endanger their proprietary software and data sets. Over time, however, the GIS industry has begun recognizing the benefits of strengthening ties with the user community by establishing policies that ease the burden of sharing data.

Advances in Hardware and Software

Although the microcomputer was developed in the 1970s and implemented in schools during the 1980s, little emphasis was placed on geography education using computers until the 1990s. Improvements in software usability throughout the 1990s enabled students and teachers to explore and develop skills with GIS. *Idrisi* software, developed by the School of Geography at Clark University, Massachusetts, allows selection of all functions via a series of pull-down menus. While ESRI's *ArcInfo* evolved into a software package with over 1,000 commands and its own macro language, *ArcView* by the same company was designed in part by the educational consortium of the NCGIA. *ArcView* performs fewer functions than *ArcInfo*, but allows proficiency within a much shorter period of time. According to Weller (1993), ArcView was introduced to educators at a workshop of the annual NCGE conference in 1991. Since that time, it has become the most widely used GIS software in secondary schools. However, *MapInfo*, *MFWorks*, *Idrisi*, *AutoCad Map, Map 2000, GeoMedia Pro, Maptitude*, *Mac GIS, Atlas GIS, OSU Map*, and others are also used (Appendix A.4), each with their own network of teachers who exchange lesson plans and technical information.

Increasing software availability on the desktop platform is another reason for the spread of GIS in education. Where most GIS software packages ran exclusively on mainframe and minicomputers 15 years ago, all major GIS packages now offer multi-platform use. Where most packages ran exclusively on Unix, Vax, or other mainframe-based operating systems in the past, most software now can be operated on desktop operating systems: DOS, Windows, and Macintosh. Furthermore, increases in the size of disk drives on these desktop systems can store the geospatial data files that were prohibitively large in the past.

Decreasing hardware and software costs have also advanced the potential for educational uses of GIS. Concurrent with the cost decrease has been an increase in processing power and speed of even the lowest-common denominator computer that can be purchased. GIS packages, because of their many capabilities and use of large spatial datasets, have benefited from the increased computing capability. All of these advances have obvious ramifications on the educational community, which has neither the requirements nor the funds for minicomputers or high-end operating systems.

The National Geography Standards

Geography Standard One directly supports the mission of educational geographic information systems:

> "The geographically informed person knows and understands how to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective" (Geography Education Standards Project 1994: 34).

Furthermore, GIS can enable students to acquire five core skills identified by the Joint Committee on Geographic Education (1984) and reiterated in the national standards. These include asking geographic questions, acquiring geographic information, organizing geographic information, analyzing geographic information, and answering geographic questions. The standards team stated that "all of the geographic skills...can be performed by a GIS; most can be performed with far greater amounts of data more rapidly, accurately, and reliably" (Geographic Education Standards Project 1994: 256). The authors recognized the need for continued research to make the potential a reality, realizing that the standards were developed "...with geographic information systems in mind but not immediately in sight" (p. 257). New national standards in other disciplines stress an inquiry-based, applied approach. GIS is increasingly viewed as a tool that can address standards in multiple disciplines—geography, history, technology, mathematics, language arts, civics, and science. Because teachers will increasingly teach to the standards, their work will promote GIS either directly or indirectly.

Despite the interest and the claims, GIS software has been acquired by less than 2,500 out of a total of approximately 106,000 K-12 schools in the United States. Furthermore, it is unknown how many of these schools are actually using the software in their curriculum, to what extent, or the effectiveness of the tool. This body of literature is the subject of the next section.

The Effectiveness of GIS in Secondary Education

One reason for the interest in GIS is improved learning that computer technology has always promised. "Americans persistently dream about the liberating effects of technical innovations" (Cohen 1988). However, some of the current claims made by GIS advocates were made in the past by proponents of educational television and other tools that were then new to the educational scene. Teachers have weathered many trends and fads, and are wary of using methods just for the sake of "jumping on a bandwagon" that could take valuable time away from their instruction. An “ever-shifting menu of advice” faces teachers regarding what to teach with the computer—from BASIC in the 1980s to HTML in the 1990s (Cuban 1999). Research to date does not indicate that there are areas of geographic instruction for which computer-assisted teaching is essential or for which it excels over any other method (Shepherd 1983; Forer 1984). Downs (1994b) criticized the lack of empirical data that might inform decisions about setting standards, designing curricula, developing materials and teaching strategies, and implementing assessment procedures. It is still not empirically known, for example, what computerized methods have worked in the classroom, and to what degree. “There is little evidence to show that the computer has made contributions to learning in the classroom other than to help learners know how to use it” (Anglin 1995). Forsyth (1994) argued for more GIS effectiveness studies in his summary of research in geography education. “Teachers are not lazy, but they need evidence that GIS will be worth the effort,” asserted Bednarz (Environmental Systems Research Institute 1995).

Because of the scarcity of GIS-based lesson modules, the opportunity to assess these modules has not been possible until very recently. Winn, Maggio, and Wunneburger (1996) stated that GIS is entering the K-12 environment “without any set of resource or curricula materials, education, or training for teachers” (p. 928). The number one recommendation from the first national conference on educational GIS was the need for the development of GIS-based lesson modules (Barstow et al. 1994). A set of modules from UNITAR on Africa was built by Clark University for *Idrisi* software in the early 1990s (UNITAR 1993), but most GIS-based lesson modules are currently built by individual teachers working in isolated classrooms scattered across the country. Systematic, well-funded efforts tend to exist only at the university level, such as Urban World, which uses *ArcView GIS* to teach urban geography concepts (Thompson et al. 1997) and the Core Curriculum for GIS for university GIS courses from the NCGIA. Furthermore, most of the university curriculum research and development focuses on learning *about* GIS rather than *with* GIS. Secondary education projects aimed at constructing lesson modules and teacher-friendly software interfaces are few, since these efforts typically receive little attention from university-sponsored cooperative projects. Therefore, development of modules at the secondary level has not been rapid or systematic. When development does occur, it is by individual secondary teachers in their own classrooms, and therefore there is no overall assessment of module effectiveness.

Assessments of GIS to date have been conducted largely by university researchers, not secondary teachers. Studies conducted by teachers have been mostly qualitativeXintuitively, teachers feel that students have used higher-order thinking skills, but quantitative research has not been undertaken. Many studies by university researchers have been limited to the effect of GIS-based lesson modules in a small handful of classrooms (Audet 1994; Brown 1990; Weller 1993). Some of these studies have either yielded inconclusive results, or results that fail to indicate a significant difference in the geographic skills and knowledge in students using GIS versus students using traditional geographic tools. Students learn *with* the computer, not necessarily *from* the computer. “It’s kind of like asking, ‘Are pencils effective?’ It depends on what you’re going to do with them” (Viadero 1997a: 12). Linn (1995) found no significant difference between students using interactive authoring software similar to GIS versus those using traditional techniques, but observed that students preferred the computer techniques for research and presentation. However, she also noted that students did not necessarily feel that they learned more with the computer. A separate study found that students in grades 7 and 8 using GIS had an increased interest in local geography and had mastered the ability to use existing data to create maps over students who used acetate overlay analysis methods (Meyer 1996; Meyer et al. 1999). However, because of limits on time, teacher competence, capabilities of GIS software, and computer availability, no significant difference was found in the analytical skills of these two groups as measured by a location analysis test. Egbert (1994) examined interactive computer spatial analysis programs that he created, rather than evaluating commercial GIS packages. Other studies compared the effectiveness of various GIS packages for secondary education (Wardley 1997) and the effect of spatial learning styles on problem-solving using computer-based geography lessons (Molina 1997).

Richard Audet (1993) observed teachers and students in several Wisconsin schools who were learning with GIS. He found that a development of problem-solving skills grew with increasing experience with GIS. Novices were more apt to use trial-and-error strategies, act before planning a complete strategy, and rely on their own visual interpretations of information. GIS experts, by contrast, tended to conceptualize a problem in terms of its essential, or "deep structure" characteristics, make effective use of computer-based queries, and develop effective representations for communicating their findings (supported by Barstow 1994). Audet and Abegg (1996) analyzed student effectiveness through expert and novice-based problem-solving behaviors, and found that as students progressed in GIS, their problem-solving skills improved to include more higher-level cognitive operations. A separate study of teachers found a significant increase in 14 measures of teachers' self-reported skill levels in an assessment of the effectiveness of GIS training (McClurg and Buss 1999; Buss and McClurg 1999). Bednarz (1997) explored the relationship between thinking style and success in learning and using GIS by examining cognitive science and applying Sternberg's theory of mental self-government.

Teachers are asking for lesson modules illustrating how to implement national, state, and district educational standards in the classroom. This is of particular importance concerning geography: Because of its long neglect in American secondary education, many teachers who have not taught geography before are suddenly being required to teach it with little training in the discipline. GIS-based lesson modules are one means to incorporate these standards, yet few modules exist that incorporate them. Whereas studies have analyzed standards implementation (such as Rooney 1997), no study has analyzed the effectiveness of GIS in addressing these standards. Neither has the effectiveness of standards-based geography education been thoroughly examined.

Computer-aided instruction is well-established with a fairly long history of successes (Kulik 1994). By the late 1990s, animations, interactive web sites, authoring software, virtual reality, slideshows with sound, video production, and other multimedia allowed students to take more control of their own learning of technology and content. Studies (for example, Bialo and Sivin-Kachala 1994) show that students using advanced technologies explore information in many forms, become more confident, communicate effectively about complex processes, become independent learners, and work well collaboratively. Using the computer to teach geography, Dove (1988) noted increased student interest, provision of new approaches for teachers, and allowed certain goals to be achieved with an increase in efficiency. In a Grade 5 classroom in Missouri, GIS motivated students to learn geography, allowed for the practice of geographic skills, and encouraged responsibility to make their own decisions, despite the fact that only one computer existed in the classroom (Keiper 1999). However, no studies could be found that demonstrate an increase in content knowledge for students using GIS.

Glenna and Melmed (1996) summarized the difficulty of evaluating the effects of technology with traditional methods. Most available tests do not reliably measure the outcomes sought, and the dynamic nature of technology makes meaningful evaluation difficult. Furthermore, assessments of the impact of technology are really assessments of the instructional *processes* enabled by technology, and the outcomes are highly dependent on instructional design, content, and teaching method. Numerous factors affect student learning, such as the classroom, school, district, and community environment, teacher's instructional style, student learning style, student personality, home situation, parental support, student and teacher interest in the subject, and variety and quality of instructional materials. These dynamics make it extremely difficult to isolate the effect of any single factor, such as technology.

Despite the many advances in GIS technology, none of the advances have been assessed as to their effect on teaching and learning. Ten years after Maguire (1989) wrote that few researchers have considered how GIS can be used in schools, his argument still holds. The "bridge" identified as a need at the NCGIA GIS in the Schools workshop in 1992 (Palladino 1992) is still needed eight years later. A bridge to secondary schools is needed from GIS applications used in businesses, government, and universities, which should include information on GIS for teachers and students, instructional materials, and suitable software.

Bednarz has claimed that "in order to continue the diffusion of GIS, a justification for using it to teach geography is needed" (1995: 45). This is because every new technology has promised better motivation, instruction, and learning, making teachers wary of technology-driven change. Effectiveness research is needed to inform implementation efforts and school reform.

Summary

The first goal of this study was to describe the extent to which GIS is implemented in secondary education in the United States. A review of the related research showed that although GIS and educational reform in geography are each *separately* in the mainstream of research, the *combination* of GIS and education clearly is on the periphery. Most of the literature on the extent of implementation came from anecdotal accounts, rather than from national or regional analyses. These accounts indicated that GIS is slowly spreading through the secondary curriculum, beginning with science and extending to geography and other social studies, largely through the efforts of individual teachers.

This study's second goal was to explain why and how GIS is implemented through an analysis of challenges and catalysts. Diffusion research and a few GIS implementation models provided a framework within which to analyze implementation. The educational reform movement's emphases on constructivism, authentic practice and assessment, school-to-career, school-to-community, student-centered learning, national standards, accountability, globalization, inquiry, information literacy, and computer literacy have combined to encourage GIS use in schools. Universities, government agencies, GIS software companies, professional societies, and advances in hardware, software, and data have helped GIS spread from universities, government, and business to secondary education. Challenges to GIS implementation arise from the fact that educators are using the same complex tool that business and industry use, but are constrained by the structure of the school system, classroom logistics, and insufficient hardware, software, lesson modules, background in exploratory teaching, background in spatial analysis, and training.

Influences on GIS in education can be classified as societal, educational, and technological. Societal influences include an increasing interest in geography and on interconnected study that emphasize the world as a "global village." Educational influences include the standards movement and educational reform. Technological influences are decreasing costs, increasing capabilities, and data availability. A circular cause-and-effect may exist—technology can transform education, but educational reform makes schools ripe for technology.

Most literature comes from educational technology research rather than geography. Therefore, whereas existing research offers some insight to implementation, the question remains of how challenges and catalysts affect why and how GIS is implemented in geography education.

This study's third goal was to assess the effectiveness of GIS on secondary geography teaching and learning. Studies thus far showed mixed results in a few classrooms scattered across the country. GIS-based lesson modules are few and the technology is largely untested. Teachers and researchers were unified in their call for more research on GIS to allow for more effective decision-making concerning its educational use.

The expansion of GIS as an educational tool, despite its slow diffusion in education compared to business and industry, far outpaces the associated research in its implementation and effectiveness. Research thus far has emphasized teaching *about* GIS, rather than teaching *with* GIS. Until more educators and researchers become aware of the potential for GIS for furthering educational reform goals, its implementation is likely to proceed slowly. It is still unclear how and why GIS is being implemented in the high school curriculum both on a national level and within individual schools, and what difference it really makes in education.

The next three chapters of this dissertation are organized to address the three research questions. Chapter 3 describes the results of a national survey to understand the *implementation* of GIS in secondary education. Chapter 4 discusses the results of experiments conducted in three high schools to assess the *effectiveness* of GIS. Chapter 5 analyzes the results of three case studies for the purpose of understanding both the *implementation and effectiveness* of GIS in these three high schools with implications for the nation. Included in each chapter is a detailed description of the data and methodology behind the national survey, experiments, and case studies.